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Electromagnetic Actuator and Method for Adjusting Said Electromagnetic Actuator

The invention relates to an electromagnetic actuator according to the preamble of the patent claim 1 and a method for the adjusting of an electromagnetic actuator according to the preamble of the patent claim 6.

An electromagnetic actuator for operating a gas exchange valve in an internal combustion machine is known from the DE 196 31 909 A1. The actuator comprises two electromagnets arranged at a spacing distance relative to one another, and an armature that is in operative connection with the gas exchange valve and that is movable back and forth by magnetic force between the electromagnets against the force of two respectively counteracting springs. The actuator further comprises setting means, with which the position of the armature is set to the geometric center position between the two end positions of the armature in connection with de-energized electromagnets. In this regard, the high dependency of the energy requirement of the actuator on production tolerances is found to be disadvantageous.

Therefore, the invention is based on the object to provide an electromagnetic actuator according to the preamble of the patent claim 1, of which the energy requirement slightly depends on the production tolerances. The invention is further based on the object to provide a method according to the preamble of the

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patent claim 6, through which the dependency of the energy requirement of the actuator on production tolerances is minimized.

The object is achieved in an electromagnetic actuator according to the preamble of the patent claim 1 by the characterizing features of the patent claim 1, and in a method according to the preamble of the patent claim 7 by the characterizing features of the patent claim 7.

Advantageous embodiments and further developments are evident from the dependent claims.

According to the invention, the springs are pre-stressed in such a manner that the same energy will be stored in both springs in connection with a compression of the springs respectively by a spring travel distance prescribed by the limited stroke travel distance of the armature. Hereby one achieves, that the armature, when it is released from its two end positions and freely oscillates, will approach close to the two electromagnets to the same extent. As a result thereof, the influence of production-necessitated tolerances of the components, and especially of the springs, on the oscillating behavior of the armature is reduced. Moreover, the total energy requirement of the actuator is optimized, because both electromagnets comprise the same current requirement due to the armature approaching equally closely to the two electromagnets. Namely, if the armature would approach more closely to the one electromagnet than to the other during the free oscillation, then the current requirement of the one electromagnetic would drop by a certain amount, but the current

requirement of the other electromagnet would increase by a multiple of this amount, so that also the total energy requirement of the actuator would increase relative to the optimal value.

Preferably, at least one of the springs comprises a non-linear spring characteristic, advantageously a characteristic with a maximum value at a position of the armature lying between the electromagnets. Due to the non-linear spring characteristic of one or both of the springs, it is on the one hand ensured that the armature is accelerated with large forces, which has a high switching frequency as a result, and on the other hand one thereby achieves that small forces act in the end positions of the armature, so that also the energy requirement of the actuator for holding the armature in its end positions is small.

For the adjustment of this electromagnetic actuator, for each spring the course or progression of the spring force is measured, which spring force arises if the respective spring is compressed by a spring travel distance corresponding to the stroke travel distance of the armature. The energy, which is stored in the respective spring due to the compression thereof, is determined from the measured curves or progressions of the spring forces. Next, the pre-stressing of one or both springs is set in such a manner that the same energy is stored in both springs.

The adjustment of the actuator can be carried out during the manufacturing of the actuator, but an adjustment during the operation is also conceivable, in order to compensate changes of

operating values or parameters, as they may arise, for example, due to temperature effects, wear, or aging.

The invention will be described in greater detail below in connection with an example embodiment, with reference to the Figures, wherein:

Fig. 1 shows an electromagnetic actuator for operating a gas exchange valve in an internal combustion machine,

Fig. 2 shows a first force versus travel distance diagram with spring characteristic curves,

Fig. 3 shows a second force versus travel distance diagram with spring characteristic curves.

According to the Fig. 1, the actuator according to the invention comprises a push rod or valve stem 4 that is in force transmitting cooperation with a gas exchange valve 5, an armature 1 secured with the valve stem 4 perpendicularly to the valve stem longitudinal axis, an electromagnet 3 acting as a closing magnet as well as a further electromagnet 2 acting as an opening magnet, which is arranged spaced apart from the closing magnet 3 in the direction of the valve stem longitudinal axis. The electromagnets 2, 3 respectively comprise an energizing or exciting coil 20 or 30, and pole surfaces lying across from one another. By means of an alternating energization of both electromagnets 2, 3, that is to say the exciting coils 20 or 30, the armature 1 is moved back and forth between the electromagnets 2, 3 along a

~~stroke travel that is limited by the electromagnets 2, 3. A spring arrangement with a first spring 61 acting in the opening direction onto the armature 1 and a second spring 62 acting in the closing direction onto the armature 1 effectuate that the armature 1 is held in a neutral equilibrium position between the electromagnets 2, 3 in the de-energized condition of the exciting coils 20, 30. Furthermore, adjusting or setting means 71, 72 for setting the pre-stressing of the springs 61, 62 are provided. The setting means 71, 72 may, for example, be embodied as disks, which effectuate a compression of the springs 71, 72, and thereby prescribe the pre-stressing of the respective springs 71, 72. They may, however, also be controllably embodied, and enable a stepless variation of the pre-stressing.~~

Sub B1 Contd

For starting the actuator, one of the electromagnets 2, 3 is energized, that is to say switched on, by applying an exciting voltage to the corresponding exciting coil 20 or 30, or a transient start-up oscillation routine is initiated, by means of which the armature 1 is first set into oscillation by alternating energization of the electromagnets 2, 3, in order to strike against the pole surface of the closing magnet 2 or the pole surface of the opening magnet 3 after a start-up oscillation transient time.

With a closed gas exchange valve 5, the armature 1 lies against the pole surface of the closing magnet 3 as shown in Fig. 1, and it is held in this position - the upper end position - as long as the closing magnet 3 is energized. In order to open the gas exchange valve 5, the closing magnet 3 is switched off, and next

the opening magnet 2 is switched on. The first spring 61 acting in the opening direction accelerates the armature 1 through or beyond the rest position. By means of the opening magnet 2 which is now energized, additional kinetic energy is supplied to the armature 1, so that it reaches the pole surface of the opening magnet 2 despite possible friction losses, and there - at the bottom end position which is shown with dashed lines in Fig. 1 - is held until the switching off of the opening magnet 2. For the renewed closing of the gas exchange valve 5, the opening magnet 2 is switched off and the closing magnet 3 is next again switched on. The armature 1 is thereby moved by the second spring 62 to the closing magnet 3 and is held there on its pole surface.

The stroke travel distance Im of the armature 1, over which the armature 1 travels - the motion of the armature 1 is referred to as flight in the following - is limited due to the prescribed spacing distance between the electromagnets 2, 3. The progressions of the spring forces of the two springs 61, 62, that is to say the forces with which the springs 61, 62 act on the armature 1, are dependent on the armature position I and can be described in connection with spring characteristic curves. In the force versus travel distance diagram of Fig. 2, the spring characteristic curve of the first spring 61 is referenced with F1, and the spring characteristic curve of the second spring 62 is referenced with F2. During the flight of the armature 1 from the upper end position to the lower end position, that is to say from the armature position 0 to the armature position Im, the force of the first spring 61 increases at first from a holding value F11 to

a maximum value F13, which is achieved at the armature position Ix, in order to thereafter fall off to an end value F10 lying below the holding value F11, whereby the end value F10 is achieved at the armature position Im, that is to say in connection with the armature 1 lying against the opening magnet 2. In contrast, the spring force of the second spring 62 increases from an end value F20, which is effective in the in the upper end position of the armature 1, monotonously but non-linearly to a holding value F21, which is achieved in the lower end position of the armature 1. The end values F10, F20 give the pre-stressing of the respective spring 61 or 62; they are adjusted or set in such a manner so that the area A1 under the spring characteristic curve F1 is equal to the area A2 under the spring characteristic curve F2. The areas A1 and A2 in that context correspond to the energy that is stored in the respective spring 61, 62, if these are compressed due to the motion of the armature. The two spring characteristic curves 61, 62 intersect each other at a point that prescribes the energetic center position Ie of the armature 1; this energetic center position Ie, which the armature 1 takes up with de-energized electromagnets 2, 3, generally does not correspond with the geometric center position between the electromagnets 2, 3 in connection with springs with different spring characteristic curves.

Sub B2 cont'd

On the one hand, the substantial advantage of the first spring 61, due to the maximum value F13 of its spring characteristic curve F1, is that it is in the position to store so much energy, that the armature 1 will be moved with high velocity during the de-stressing of the first spring 61, which leads to short switch-

ing times, despite the small holding value F11. Due to the small holding value F11, on the other hand, the current requirement for holding the armature 1 in its upper end position, and therewith the energy requirement of the actuator, is small.

In the force versus travel distance diagram according to Fig. 3, the spring characteristic curve F2 of the second spring 62, with an increasing spacing distance I between armature 1 and closing magnet 2, comprises at first a decreasing progression, then an increasing progression, and thereafter again a decreasing progression. The areas A1, A2 under the spring characteristic curves F1, F2 of the springs 61, 62 are once again equally large. For these spring characteristic curves F1, F2 it is shown to be advantageous, that the difference ΔF between the two spring characteristic curves F1, F2, that is to say the resulting force acting on the armature 1, is large for a large range of the spacing distance I between the armature 1 and closing magnet 3. As a result of that, the gas exchange valve 5 may also be opened against a combustion chamber internal pressure, that is to say the energy requirement of the opening magnet 2 is small due to the high resulting force ΔF that is effective during the opening process.

The adjustment of the actuator is carried out before the installation of the actuator in the internal combustion machine. Thereby, first the pre-stressing of the second spring 62 is adjustingly set to the end value F20, at which a secure or reliable closing of the gas exchange valve 5 is ensured. Next, the second spring 62 is compressed by the spring travel distance

corresponding to the stroke travel distance Im of the armature 1, and the progression of the spring force, which results thereby, is measured section-wise and integrated section-wise over the spring travel distance. The result of this integration corresponds to the energy that is stored in this context in the second spring 62. Thereby, the measurement of the spring force can be carried out by means of a load cell or a measuring gage.

The energy that is stored in the first spring 61 if the armature 1 is moved from its lower end position to its upper end position, is also measured in the same manner as described above, namely by measuring the progression of the spring force of the first spring 61 that results from the armature motion, and by integration of this progression over the spring travel distance, through which the first spring 61 is thereby compressed. Next, the energy values that have been determined in this manner are compared with one another, and the pre-stressing of the first spring 61 is adjustingly set in such a manner so that the same energy is stored in the two springs 61, 61, if these are compressed by the stroke travel distance Im. The actuator is only installed into the internal combustion machine after this adjustment.

In the present example embodiment, the actuator is adjusted before placing it into operation. Also conceivable, however, are an adjustment during the operation, and an after-adjustment dependent on operating parameters. In this case, the adjusting or setting means are controllably embodied, and the progressions of the spring forces are measured with measuring means, onto which the springs act, for example with pressure sensors, espe-

cially with piezocrystals. The adjusting or setting means are then controlled by control means, dependent on the measured spring forces, in such a manner so that the same energy is stored in both springs in connection with the maximum compression of the springs 61, 62 that is possible during the operation.